(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 December 2002 (05.12.2002)

PCT

(10) International Publication Number
WO 02/097854 A2

(51) International Patent Classification[7]: H01J 37/32

(21) International Application Number: PCT/RU02/00236

(22) International Filing Date: 17 May 2002 (17.05.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2001114393 30 May 2001 (30.05.2001) RU

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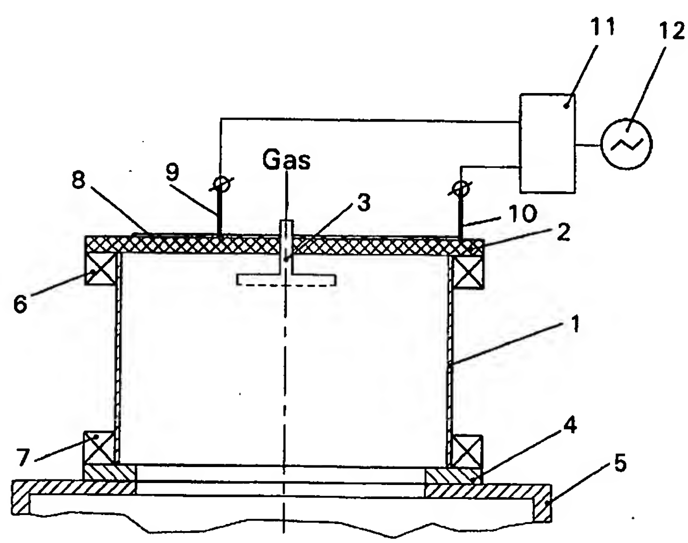
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),

[Continued on next page]

(54) Title: PLASMA REACTOR AND PLASMA GENERATING APPARATUS



(57) Abstract: A plasma reactor comprises a discharge chamber with a gas distributor (3), a substance treatment chamber, a magnetic system (6, 7) for generating in the discharge chamber of a stationary inhomogeneous magnetic field, and a RF power input unit (8) composed of two sections. According to the first embodiment of the invention, the first section is made in the form of parts of electrical conductor connected in series and arranged on the outside of dielectric wall (2) of the discharge chamber. The second section is made in the form of spiral electrical conductor. According to the second embodiment of the invention, the first and second sections of the RF power input unit (8) are made in the form of oppositely directed spirals. The shape of the RF power input unit (8) allows a formation with spatially homogeneous, dense plasma to be generated, which may be used for uniform material treatment.

WO 02/097854 A2

Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

PLASMA REACTOR AND PLASMA GENERATING APPARATUS

Field of the Invention

A cluster of inventions relates to a plasma technique and a process for plasma treatment of material surfaces. The inventions may be employed in various processes using homogeneous high-density plasma generation and also in charged particle sources used for material etching, sputtering, ionic assistance, ion beam implantation, as well as for performing other operations pertinent to the modification of surfaces to be treated.

Prior art

Various types of plasma reactors and plasma generating apparatuses incorporated in said plasma reactors are currently known. Plasma reactors that have gained the widest acceptance in recent years are generally based on the usage of high frequency excitation of a gas discharge. Among these is a plasma reactor described in an international application WO 91/10341 (IPC H05H 1/24, H05H1/46, published 11.07.91).

A known plasma reactor contains an axially symmetric discharge chamber and an inductor located on the discharge chamber side wall and switched to a first RF voltage source. A heavy electrode connected to a second RF voltage source is arranged in a materials plasma treatment chamber. A magnetic system fixed on an upper end wall of the discharge chamber is made in the form of parallel permanent magnet assemblies adapted for generating in the discharge chamber cavity of a stationary inhomogeneous magnetic field reducing from the chamber walls towards the central part thereof. The given embodiment of the magnetic system allows the losses of RF power supplied to a discharge volume to be reduced owing to the magnetic insulation of the discharge chamber walls. In addition, the interaction of a stationary magnetic field and a RF field increases the efficiency of the working gas ionization due to the electron drift in the crossed and magnetic fields. An electromagnetic coil connected to a direct voltage source and an outer magnetic circuit may be used for creating a magnetic field in such a reactor. The reactor further includes a gas distributor and a system for withdrawal of a gas from the plasma treatment chamber. The known plasma reactor increases to a certain extent a spatial homogeneity of a plasma formation, which constitutes an ion and radical source for material treatment.

Also known are spatially homogeneous plasma generating apparatuses consisting of a discharge chamber, a RF power input unit, in particular, the one made in the form of an inductor located on the discharge chamber walls, and a magnetic system for creating in the

discharge chamber of an inhomogeneous stationary magnetic field, which reduces from the discharge chamber walls to the central part thereof (see, for example, an international application WO 94/06263, IPC H05H 1/46, published 17.03.1994).

In order to improve the homogeneity of plasma generated, RF power input units are utilized, which are formed as curved parts of a conductor connected in series one with another through closing elements and switched to a RF generator (see, for example, a European application EP 0 648 069 A1, IPC H05H 1/46, H01J37/32, published 12.04.1995). Such RF power input unit may be arranged in a discharge volume within the region of the stationary magnetic field having reduced induction. When arranged in such a manner, the power input unit divides the discharge chamber into two volumes with independent supplying of a working gas. Gas discharge plasma generated in each of the two volumes has uniformly distributed density of charged particles. However, such embodiment has substantial disadvantages related with the complexity of construction, the intricacy of power and gas supply systems.

Many of the solutions are directed to modifying the RF power input unit for the purpose of increasing the uniformity of charged particle density distribution in gas discharge plasma, i.e., for increasing the spatial homogeneity of the plasma formation. As an example, a European application EP 0 710 055 A1 (IPC H05H 1/46, H01J 37/32, published 01.05.1996) describes a plasma reactor including a RF power input unit composed of electrical conductors curved so as to form a multiple-thread spiral. Such unit is fixed to a plasma reactor discharge chamber end wall made of dielectric material. The conductors are connected in a central point which is at the ground potential, and the conductors peripheral parts are connected parallel to a first RF generator. The material to be treated (substrate) is arranged on an electrode connected to a second RF generator. The employment of such RF power input unit increases the uniformity of the RF electrical field distribution within the volume of the gas discharge plasma. The RF power input unit may include an additional (second) section designed as an inductor made in the form of a multiple-thread spiral which is connected in series with respective coils of a first section.

The closest prior invention with regard to the first embodiment of the patentable plasma reactor and the plasma generating apparatus incorporated therein are the respective reactor and the associated apparatus disclosed in a European application EP 0 633 713 A1 (IPC H05H 1/46, H01J37/32, published 11.01.1995). The known plasma reactor includes a discharge chamber with a gas distributor, a plasma treatment chamber for treating a material in the from of a substrate, a magnetic system for creating a stationary inhomogeneous

magnetic field in the discharge chamber cavity, and a RF power input unit with a section made in the form of parts of an electrical conductor connected in series one with another. The said section of the RF power input unit is arranged on the outside of the discharge chamber dielectric wall. The parts of electrical conductor making the mentioned section are connected in such a manner that the current flowing through opposite parts of the electrical conductor have opposite directivity. Electrical terminals of the power input unit are connected through a matching system to a RF voltage source. Although the given solution allows the uniformity of charged particles density distribution to be partially increased in the central part of the discharge chamber arranged opposite the substrate under the treatment process, the spatial homogeneity of the gas discharge plasma generated by means of such apparatus is not sufficient for treating the substrates of larger diameter (up to 300 mm and more) and larger volumes of a gaseous working substance. The reason is that zones of the discharge chamber, adjoining the walls thereof where the magnetic field induction was of maximal value and the value of RF field was minimal, were not effectively used. The indicated disadvantage is most pronounced in case a discharge chamber with elongated side walls is used.

The closest prior art with regard to the second embodiment of the patentable plasma reactor and plasma generating apparatus incorporated therein are respective reactor and apparatus disclosed in a European application EP 0 727 923 A1 (IPC H05H 1/46, H01J37/32, published 21.08.1996). The known plasma reactor includes a discharge chamber with a gas distributor, a material treatment chamber, a magnetic system for creating a stationary inhomogeneous magnetic field in the discharge chamber, and a RF power input unit composed of two or more sections. The sections of the RF power input unit are constructed from electrical conductors curved so as to form multiple-thread spirals. The first section of the RF power input unit is connected in series with the second section, and each of the sections are connected to respective RF voltage sources (see Figure 20 of a European application EP 0 727 923). The first section of the power input unit is arranged above the central part of the discharge chamber and the second section is arranged around the first section. The RF voltage sources with variable voltage frequency are adapted for connecting to the plasma generating apparatus. The objective of the given embodiment is directed to the effective use of power supplied by readjusting the optimal frequency of RF voltage sources during heating of gas discharge plasma and, respectively, varying the internal plasma frequency (the own plasma wave). The selected prototype as well as other analogues of the invention do not solve the problem related to the substantial increase in the spatial homogeneity of gas discharge plasma for discharge chambers having typical dimensions exceeding 300 mm. To provide for uniform

material plasma treatment, high plasma homogeneity with regard to the values of density and average energy of charged particles is desired, which must not exceed 10% the length of the substrate under treatment process or the size of discharge chamber.

Disclosure of the Invention

The objective of the patentable inventions is targeted at solving the problem related to the generation of a plasma formation of charged particles of partially homogeneous high density and spatial dimensions sufficient for treating articles and materials. The problem may be solved by creating plasma reactors including plasma generating apparatuses adapted for the uniform distribution of charged particles within plasma volume, with inert gases or reactive gases being used as a working medium. The indicated objective allows the following technical results to be achieved: for the patentable plasma reactor the achievable technical result is an increase in the uniformity of material treatment over the entire area of the treated surface, and for the patentable plasma generating apparatus the achievable technical result is an increase in the spatial homogeneity of the generated plasma with regard to the density and average energy of charged particles.

The above mentioned technical results may be obtained, according to the first embodiment of the invention, by means of a plasma reactor comprising a discharge chamber with a gas distributor, a substance treatment chamber, a magnetic system for creating a stationary inhomogeneous magnetic field in the discharge chamber cavity, and a RF power input unit with a first section made in the form of parts of electrical conductor connected in series one with another. The parts of the electrical conductor are arranged on the outside of at least one dielectric wall of the discharge chamber and connected in such a manner that currents flowing through opposite parts of the electrical conductor have opposite directivity. According to the present invention, the RF power input unit has a second section formed as a spiral electrical conductor. The second section is arranged on the outside of the discharge chamber, on one or several dielectric walls thereof; the first section is positioned above the central part of the discharge chamber and the second section is arranged around the first section.

Such embodiment of the RF power input unit enables uniform heating of an electronic component within the entire gas discharge plasma volume defined by the discharge chamber walls. The first section of power input unit is adapted for heating electrons in the central part of the discharge chamber by exciting internal plasma waves in the gas discharge plasma, which is in the stationary inhomogeneous magnetic field. The second section of the power

input unit provides for inductive heating of electrons in the peripheral regions of gas discharge plasma enclosed in the volume defined by the discharge chamber side walls. The uniform heating of gas discharge plasma within the entire volume of the discharge chamber provides for respective uniform spatial electron distribution with regard to the density and average energy values. It should be emphasized that the embodiment combines the possibility of heating plasma in the central part of the discharge chamber through excitation of internal plasma waves and the possibility of inductive heating of peripheral plasma zones. So the patentable apparatus differs fundamentally from known apparatuses equipped with sectioned RF power input units. Conventional devices for uniform RF heating of gas discharge plasma employ sections formed as inductors, which effectuate plasma heating only in the limited discharge volume zones. The patentable apparatuses, where the heating mechanism is realized through the simultaneous usage of excitation of internal waves and inductive heating, allow the volume of plasma with charged particles density differing by no more than 5% to be increased.

The best results with regard to plasma homogeneity (density and average electron energy) and, accordingly, with regard to the uniform properties of the treated surface are obtained when RF power input unit sections are connected in series and switched to a common RF voltage source.

The first and second sections of the RF power input unit may be connected parallel one with respect to the other or may be connected independently to respective RF generators.

The magnetic system of plasma reactor is composed of at least one magnetic field source made in the form of an electromagnetic coil mounted on the discharge chamber side wall.

The magnetic system preferably comprises at least one additional magnetic field source made in the form of an electromagnetic coil mounted on the discharge chamber end wall, which carries the RF power input unit.

The magnetic system of plasma reactor may include at least one magnetic field source made in the from of one or several permanent magnets fixed on the discharge chamber side wall.

The magnetic system may also contain at least one magnetic field source and a magnetic circuit, with the magnetic field source being arranged intermediate the discharge chamber side wall and the magnetic circuit.

The above mentioned embodiments of the magnetic system of plasma reactor provide, on the whole, the generation of a magnetic field with maximal induction value in the area

adjoining the discharge chamber walls, which reduces to the central part of the discharge chamber. Such distribution of the magnetic field is necessary for effective retaining of electrons in the discharge volume of the plasma reactor.

The above technical results are achieved by means of a plasma generating apparatus, which is an integral part of a plasma reactor and includes constructional parts identical to those of the plasma reactor except a substance treatment chamber. The apparatus, according to the present invention, provides for uniform heating of an electronic component within the entire volume of the discharge chamber, which results in high spatial homogeneity of a plasma formation (with regard to charged particles density and energy values).

The above result is also provided by means of a plasma reactor which, according to the second embodiment of the invention, comprises a discharge chamber with a gas distributor, a substance treatment chamber, a magnetic system for creating a stationary inhomogeneous magnetic field, and a RF power input unit with at least two sections. Each section is made from an electrical conductor curved so as to form a spiral with coils arranged on the outside of at least one dielectric wall of the discharge chamber. In addition, according to the present invention, the first and second sections are formed as oppositely directed spirals (for example, left-hand and right-hand spirals). The first section is arranged above the central part of the discharge chamber and the second section is arranged around the first section.

As well as in the first embodiment of the plasma reactor, the first section of the power input unit provides for heating of electrons in the central region of the discharge chamber through the excitation of internal plasma waves in the gas discharge plasma, which is within the stationary inhomogeneous magnetic field. The second section of the power input unit allows inductive heating of electrons in the peripheral zones of gas discharge plasma enclosed within the volume of discharge chamber defined by side walls. The uniform heating of gas discharge plasma within the entire volume of the discharge chamber results in the respective uniform spatial electron distribution with regard to density and average energy thereof.

The combined usage of heating plasma in the central part of the discharge chamber by excitation of internal plasma waves and the inductive heating of peripheral plasma regions in one apparatus, realized according to the second embodiment of the invention, makes it fundamentally different from known apparatuses equipped with spiral-shaped sectioned RF power input units. Conventional devices for uniform RF heating of gas discharge plasma use sections made in the form of spiral-shaped inductors which are used for heating plasma only in the limited regions of the discharge volume. In the patentable inventions (a plasma reactor and a plasma generating apparatus) the simultaneous use of the heating mechanism involving

the excitation of internal plasma waves and the inductive heating substantially increases the plasma volume with charged particles density varying by no more than 5%. The internal plasma waves excitation is implemented through the employment of RF power input unit sections made of spirally curved conductors made in the form of oppositely directed spirals (for example, a first section making a left-hand spiral and a second section making a right-hand spiral). Such embodiment of spirally curved conductors facilitates the excitation of own plasma wave during interaction of RF currents flowing through these conductors.

The best results with regard to plasma homogeneity and, accordingly, to uniform surfaces treatment are made possible by realizing the series connection of RF power input unit sections which are connected to a common RF voltage source. Parallel connection of first and second sections of the RF power input unit is also possible. The sections of the power input unit may be connected independently to the respective RF generators.

As well as in the first embodiment of the plasma reactor, the magnetic system includes at least one magnetic field source made in the form of an electromagnetic coil mounted on the discharge chamber side wall. The magnetic system may include at least one additional magnetic field source made in the form of an electromagnetic coil mounted on the discharge chamber end wall, carrying the RF power input unit.

The magnetic system of the plasma reactor may include at least one magnetic field source composed of one or several permanent magnets arranged on the discharge chamber side wall.

In addition, the magnetic system may comprise at least one magnetic field source and a magnetic circuit, with the magnetic field source being arranged intermediate the discharge chamber side wall and the magnetic circuit.

The magnetic field distribution provided by means of the cited embodiments of the magnetic system permits effective confinement of electrons in the discharge volume of the apparatus.

The above technical result is achieved by means of a plasma generating apparatus, which is an integral part of the plasma reactor realized according to the second embodiment of the invention. The apparatus includes constructional elements identical to those of the plasma reactor except a substance treatment chamber. The plasma generating apparatus also allows uniform heating of electronic component within the entire volume of the discharge chamber, resulting in high spatial homogeneity of a plasma formation (with regard to charged particles density and average energy).

Brief Description of Drawings

The advantages of a cluster of patentable inventions will become more evident by reference to the accompanying drawings.

Figure 1 is a schematic presentation of a sectional view of plasma reactor according to the first embodiment of the invention with a plasma generating apparatus;

Figure 2 is a schematic presentation of a top view of a discharge chamber end wall of the plasma reactor illustrated in Figure 1;

Figure 3 is a schematic presentation of a sectional view of a plasma generating apparatus incorporated in the plasma reactor and comprising magnetic circuits and additional magnetic field source;

Figure 4 is a schematic presentation of a sectional view of the plasma generating apparatus incorporated in the plasma reactor and comprising a magnetic field source made in the form of permanent magnet assemblies;

Figure 5 is a schematic presentation of a sectional view of a plasma reactor realized according to the second embodiment and including a plasma generating apparatus;

Figure 6 is a schematic presentation of a top view of the discharge chamber end wall of the plasma reactor illustrated in Figure 5.

Preferable Embodiments of the Invention

The plasma reactor, according to the first embodiment (see Figures 1 and 2) comprises a discharge chamber of axially symmetric shape with a cylindrical side wall 1 made of nonmagnetic material (aluminum) and an dielectric end wall 2 (quartz glass). A gas distributor 3 is arranged in upper part of the discharge chamber and designed for uniform supplying of a working gas into a discharge volume of the discharge chamber. A mounting flange 4 of the discharge chamber is connected hermetically with a mounting flange 5 of a substance plasma treatment chamber.

A magnetic system of the plasma reactor comprises electromagnetic coils 6 and 7 fixed in the vicinity of the dielectric end wall 2 and the mounting flange 4, respectively. The coils 6 and 7 are connected to a power-supply source (not shown in the drawing) to generate an inhomogeneous magnetic field which is reducing to the center of the discharge chamber.

A RF power input unit 8 (RF antenna) fixed on the dielectric end wall 2 has electric terminals 9 and 10 connected through a matching system 11 with a RF voltage source 12. The power input unit 8 is composed of two sections (see Figure 2) arranged in a common plane on the end wall 2. The first section is formed of parts of an electrical conductor 13 connected in

series one with another. The parts of the conductor 13 are arranged in parallel one with another, with currents flowing through opposite conductor parts having opposite direction. The second section is made in the form of a spiral conductor 14. The first section of the power input unit 8 is mounted above the discharge chamber central part and the second section is arranged around the first section.

In the embodiment under consideration (see Figure 2), the sections of the power input unit 8 are connected in series one with another, yet parallel connection or independent connection of the sections to respective RF voltage sources is also possible.

A plasma generating apparatus as an integral part of the plasma reactor is joined hermetically to a mounting flange 5 of the substance plasma treatment chamber (see Figures 1 and 2). The plasma generating apparatus comprises a discharge chamber with a side wall 1 and an end wall 2, a gas distributor 3, a mounting flange 4, a magnetic system with electromagnetic coils 6 and 7, and a RF power input unit 8 with electrical terminals 9 and 10, which are connected through a matching system 11 to a RF voltage source 12.

In one of the embodiments of a plasma generating apparatus illustrated in Figure 3, a magnetic system comprises an additional electromagnetic coil located on an end wall 2 of the discharge chamber. An outer diameter of an additional coil 15 is less than an inner diameter of the discharge chamber. The magnetic system is further equipped with a magnetic circuit composed of discrete magnetically permeable segments 16 circumferentially arranged equally spaced on the outside of the discharge chamber. Magnetically permeable segments 16 are adapted for equalizing the magnetic field along the inner surface of the side wall 1 of the discharge chamber. In the given embodiment the electromagnetic coils 6 and 7 are positioned between the side wall 1 and magnetically permeable segments 16.

In another embodiment of the plasma generating apparatus (see Figure 4) incorporated in the plasma reactor, the magnetic field sources are made in the form of assemblies 17 composed of discrete permanent magnets 18 fixed equally on the outside wall 1 spaced around the discharge chamber. The assemblies 17 of permanent magnets 18 are attached around the circumference of the discharge chamber intermediate the end wall 2 and the mounting flange 4. Circular magnetic circuits 19 and 20 are arranged between assemblies 17 of permanent magnets 18 and the end wall 2, as well as between assemblies 17 and the mounting flange 4 to provide for predetermined magnetic field distribution in the discharge chamber cavity. Additional magnetic circuits may be used for correcting the magnetic field distribution in different embodiments of the plasma generating apparatus and plasma reactor,

including the embodiment comprising magnetic field sources made in the form of electromagnetic coils.

The plasma reactor, according to the second embodiment of the invention (see Figures 5 and 6), comprises a discharge chamber of axially symmetric shape having a cylindrical side wall 21 of nonmagnetic material (aluminum) and a dielectric end wall 22 (quartz glass). A gas distributor 23 is located in the upper part of the discharge chamber. A mounting flange 24 of the discharge chamber is connected hermetically to a mounting flange 25 of a working substance plasma treatment chamber. A magnetic system of the plasma reactor comprises electromagnetic coils 26 and 27 connected to a current source (not shown in the drawing).

A RF power input unit 28 mounted on the dielectric end wall 22 is equipped with terminals 29 and 30, which are connected through a matching system 31 to a RF voltage source 32. The power input unit 28 is composed of two sections (see Figure 6) arranged in a common plane on the end wall 22. The first and second sections are made in the form of spiral electrical conductors 33 and 34, respectively. The plasma reactor, according to the second embodiment of the invention, is characterized in that the first and second sections of the power input unit 28 are made in form of oppositely directed (left-hand and right-hand) spirals. The first section of the power input unit 28 is disposed above the discharge chamber central part and the second section is arranged around the first section.

In the embodiment under consideration (see Figure 5), sections of the power input unit 28 are connected in series one with another, but it is not inconceivable that the sections be parallel connected or an independent connection to the respective RF voltage source is possible.

A plasma generating apparatus as an integral part of the plasma reactor, according to the second embodiment of the invention, is connected hermetically to a mounting flange 25 of the substance plasma treatment chamber (see Figures 5 and 6). The plasma generating apparatus comprises a discharge chamber with a side wall 21 and an end wall 22, a gas distributor 23, a mounting flange 24, a magnetic system with electromagnetic coils 26 and 27, and a RF power input unit 28 with electrical terminals 29 and 30, which are connected through a matching system 31 to a RF voltage source 32.

In one of the embodiments of plasma generating apparatus – similar to the respective embodiment of plasma generating apparatus realized according to the first embodiment of the invention (see Figure 3) – a magnetic system may comprise an additional electromagnetic coil located on the end wall 22 of the discharge chamber. The magnetic system may be further equipped with a magnetic circuit composed of discrete magnetically permeable segments,

which are circumferentially arranged equally spaced on the outside of the discharge chamber. In the given embodiment, electromagnetic coils 26 and 27 are located intermediate the side wall 21 and magnetically permeable segments.

In another example of the embodiment of plasma generating apparatus – similar to the respective example of plasma generating apparatus of the first embodiment of the invention (see Figure 4) – the magnetic field sources are made in the form of permanent magnet assemblies arranged equally spaced on the outside of the side wall 21 around the discharge chamber.

According to the first embodiment of the invention, the plasma reactor and the plasma generating apparatus incorporated therein operate as follows.

The inert working gas such as argon is uniformly supplied into the discharge chamber cavity via a gas distributor 3 (see Figures 1 and 2). A reactive gas may be used as a working gas. A stationary inhomogeneous magnetic field is generated in the discharge volume enclosed by a side wall 1 and an end wall 2 of the discharge chamber upon passage of current through electromagnetic coils 6 and 7. The magnetic field induction value is selected with the provision that upon input of RF power the own plasma wave are excited in the central part of the discharge chamber. The magnetic field generated by means of electromagnetic coils 6 and 7 is reducing from the side wall 1 towards the discharge chamber central part. Such nature of the magnetic field distribution ("magnetic wall" effect) facilitates the confinement of electrons in the discharge volume, when the RF power is intensively supplied into the discharge chamber. The most effective confinement of charged particles in the discharge volume and, accordingly, the most effective use of RF power supplied is achieved through the employment of additional electromagnetic coil 15 and an outer magnetic circuit composed of magnetically permeable segments 16 (see Figure 3). The use of additional elements of the magnetic system allows the isolating magnetic field to be uniformly distributed not only along the surface of the side wall 1 but also along the surface of end wall 2.

In one of the embodiments of the plasma reactor and the plasma generating apparatus (see Figure 4), a magnetic field may be generated by means of permanent magnets 18 formed as assemblies 17 arranged at an equal distance one from another around the discharge chamber between the end wall 2 and the mounting flange 4. The distribution of the magnetic field generated by means of such magnetic system within the discharge chamber is corrected by annular magnetic circuits 19 and 20, which are arranged intermediate the assemblies 17 and the end wall 2, as well as between the assemblies 17 and the mounting flange 4.

Subsequent to filling the discharge chamber with argon and creating a stationary inhomogeneous magnetic field of predetermined configuration, the RF voltage source 12 is turned on, and the RF power is supplied by means of the power input unit 8 switched through the matching system 11 and electrical terminals 9 and 10 to the RF voltage source 12 into the discharge chamber through the dielectric end wall 2.

The uniform and effective heating of electronic component within the entire discharge volume is provided by employing the power input unit 8 realized according to the present invention. The first section of the power input unit 8 composed of parts of conductor 13, which are arranged in parallel and connected in series (see Figure 2), is adapted for exciting the internal plasma waves in the discharge volume owing to interaction between the stationary magnetic field and an electrical component of the RF field generated. The excitation of internal plasma waves occurs on flowing of alternating RF current through opposite parts of the conductor 13 in opposite directions (see Figure 2). The dimensions and number of conductor parts are selected such that the plasma is generated with maximal density and homogeneity in the treated sample area.

The second section of the RF power input unit 8 made in the form of a spiral conductor 14 provides for excitation in the peripheral annular region of the discharge chamber of a RF induction discharge and for inductive electron heating.

The studies were conducted and the results were as follows.

With argon used as a working gas, the frequency of discharge generated in the discharge chamber was selected within the range of 10 to 100 MHz depending on the desired plasma density. The value of RF power supplied to the discharge chamber by means of RF power input unit 8 was from 20 W to 2 kW. The maximal magnetic field induction value of the discharge chamber walls varied within the range of from 0.01 to 0.1 T. The plasma density value varied depending on the power supplied from $10\cdot10^{9}$ to $10\cdot10^{11}$ cm^{-3}. At the fixed value of RF power supplied to the discharge chamber, a homogeneous plasma formation of 240 mm diameter has been produced in the discharge chamber cavity of 500 mm diameter and 100 mm height. Inhomogeneity of the plasma formation with regard to the values of density and the average electron radial energy did not exceed 5%. The respective results as to the treatment uniformity were obtained upon plasma treatment of a substrate of 300 mm diameter, which was located opposite the emission exit opening of the discharge chamber.

The plasma reactor and plasma generating apparatus incorporated therein, which are implemented in accordance with the second embodiment of the invention, operate in the manner similar to that of the first embodiment of the invention.

The working gas (argon) is supplied into the discharge chamber through the gas distributor 23 (see Figures 5 and 6). A stationary inhomogeneous magnetic field is generated in the discharge volume enclosed by the side wall 21 and the end wall 22 of the discharge chamber upon passage of current through the electromagnetic coils 26 and 27. The magnetic field generated by means of coils 26 and 27 is reducing from the side wall 21 towards the central part of the discharge chamber.

The most effective confinement of charged particles in the discharge volume and, accordingly, the effective use of the RF power supplied is achieved owing to the employment of an additional electromagnetic coil and an outer magnetic circuit made in the form of magnetically permeable segments (similar to the first embodiment of the invention illustrated in Figure 3).

In one of the embodiments of the plasma reactor and plasma generating apparatus (similar to the realization thereof in the first embodiment of the invention illustrated in Figure 4), the magnetic field may be generated by means of permanent magnets made in the form of assemblies arranged at an equal distance one from another around the discharge chamber between the end wall 22 and the mounting flange 24.

Subsequent to filling the discharge chamber with argon and generating a stationary inhomogeneous magnetic field of predetermined configuration within the discharge volume, the RF voltage source 32 is turned on. The RF power is supplied by the power input unit 28 connected through the matching system 31 and electrical terminals 29 and 30 with the RF voltage source 32 into the discharge chamber through the end wall 22.

The uniform and effective heating of electronic component within the entire discharge volume is performed through the employment of the power input unit 28 realized in accordance with the second embodiment of the invention. The power input unit 28 having two sections made in the form of spiral electrical conductors 33 and 34 (see Figure 6) provides excitation in the discharge volume of the internal plasma waves due to the interaction of the stationary magnetic field and the electrical component of the generated RF field. The internal plasma waves are excited during flowing of alternating RF currents of opposite directivity through electrical conductors 33 and 34. The flow of currents of opposite directivity through conductors 33 and 34 and, accordingly, the generation of the RF field (excitation of the own plasma wave) during currents interaction are provided due to the fact that first and second sections of the power input unit 28 are made in the form of oppositely directed spirals. The dimensions and the number of coils of the first and second sections are selected such that the plasma is generated with maximal density and homogeneity in the treated sample area.

The given technical results achieved are proved by the tests. The above conditions, at which were tested the plasma reactor and the plasma generating apparatus incorporated therein, according to the first embodiment of the invention, permitted the achievement of the following result for the second embodiment of the invention. At the fixed value of RF power supplied to the discharge chamber, a homogeneous plasma formation of 300 mm diameter has been produced in the discharge chamber volume of 500 mm diameter and 150 mm height. The outer diameter of the RF power input unit located on the discharge chamber end wall was 420 mm. Inhomogeneity of the plasma formation with regard to the density and average energy of electrons in the radial direction did not exceed 5%.

The respective results as to the treatment uniformity were produced upon plasma treatment of a 300-mm diameter substrate, which was arranged opposite the emission exit opening of the discharge chamber.

Industrial Application

The patentable cluster of inventions may be used in the development of processing equipment for implementation of plasma and beam treatment of articles and materials, including semiconductive materials. The generation of high-density homogeneous plasma formations of sufficiently large dimensions (up to 300 mm and more) with the employment of facilities based on the patentable cluster of inventions, allows various continuous processes to be implemented, including coating application, ion implantation, ion assistance, surface cleaning and materials surface modification.

While the patentable inventions are illustrated and described on the examples of preferable embodiments, it will be appreciated by those skilled in the art that various changes can be made therein for specific industrial implementation of the patentable inventions without departing from the spirit and scope of the inventions. The embodiments of the inventions are within the scope of the following claims.

CLAIMS

What we claim is:

1. Plasma reactor including a discharge chamber with a gas distributor (3), a substance plasma treatment chamber, a magnetic system for generating in the discharge chamber cavity of a stationary inhomogeneous magnetic field, a RF power input unit with a first section made in the form of parts of an electrical conductor (13) connected in series and arranged on the outside of at least one dielectric wall (2) of the discharge chamber and connected in such a manner that the currents flowing through opposite parts of the electrical conductor (13) have opposite directivity, is characterized in that the RF power input unit has a second section made in the form of spiral electrical conductor (14) and arranged on the outside of a discharge chamber, on one or several dielectric walls thereof, with said first section being arranged above a central part of the discharge chamber and said second section being disposed around said first section.

2. Plasma reactor as claimed in claim 1, wherein said first and second sections of said RF power input unit are connected in series one with another.

3. Plasma reactor as claimed in claim 1, wherein said first and second sections of said RF power input unit are connected in parallel one with another.

4. Plasma reactor as claimed in claim 1, wherein said first and second sections of said RF power input unit are connected independently to RF generators.

5. Plasma reactor as claimed in claim 1, wherein a magnetic system includes at least one magnetic field source made in the form of an electromagnetic coil (6 or 7) located on a side wall (1) of said discharge chamber.

6. Plasma reactor as claimed in claim 5, wherein said magnetic system includes at least one additional magnetic field source made in the from of an electromagnetic coil (15) located on an end wall (2) of said discharge chamber on which is located said RF power input unit.

7. Plasma reactor as claimed in claim 1, wherein said magnetic system includes at least one magnetic field source made in the form of one or several permanent magnets (18) located on said side wall (1) of said discharge chamber.

8. Plasma reactor as claimed in claim 1, wherein said magnetic system includes at least one magnetic field source (6 or 7) and a magnetic circuit (16), with said magnetic field source (6 or 7) being located intermediate said side wall (1) of the discharge chamber and said magnetic circuit (16).

9. Plasma generating apparatus comprising a discharge chamber with a gas distributor (3), a magnetic system for generating in a discharge chamber cavity of a stationary inhomogeneous magnetic field, a RF power input unit with a first section made in the form of parts of electrical conductor (13) connected in series and arranged on the outside of dielectric wall (2) of said discharge chamber, with said parts being connected so that currents flowing through opposite parts have opposite directivity, is characterized in that said RF power input unit comprises a second section connected to said first section made in the form of spiral electric conductor (14), with said second section being arranged on the outside of said discharge chamber, on one or several dielectric walls thereof, said first section being arranged above the central part of said discharge chamber and said second sector being arranged around said first section.

10. Apparatus as claimed in claim 9, wherein said first and second sections of said RF power input unit are connected in series one with another.

11. Apparatus as claimed in claim 9, wherein said first and second sections of said RF power input unit are connected in parallel one with another.

12. Apparatus as claimed in claim 9, wherein said first and second sections of said RF power input unit are independently connected to RF generators.

13. Apparatus as claimed in claim 9, wherein a magnetic system includes at least one magnetic field source made in the form of an electromagnetic coil (6 or 7) located on said side wall (1) of a discharge chamber.

14. Apparatus as claimed in claim 13, wherein a magnetic system includes at least one additional magnetic field source made in the form of an electromagnetic coil (15) located on said end wall (2) of a discharge chamber on which is arranged a RF power input unit.

15. Apparatus as claimed in claim 9, wherein a magnetic system includes at least one magnetic force source made in the form of one or several permanent magnets (18) located on the side wall (1) of discharge chamber.

16. Apparatus as claimed in claim 9, wherein a magnetic system includes at least one magnetic field source (6 or 7) and a magnetic circuit (16), with said magnetic field source (6 or 7) being arranged intermediate said side wall (1) of discharge chamber and said magnetic circuit (16).

17. Plasma reactor comprising a discharge chamber with a gas distributor (23), a substance treatment chamber, a magnetic system for generating in the discharge chamber cavity of a stationary inhomogeneous magnetic field, a RF power input unit with at least two sections, each being made in the form of spiral electrical conductor (33 and 34), with coils thereof being arranged on the outside of at least one dielectric wall (22) of discharge chamber, is characterized in that first and second sections of said RF power input unit are made in the form of oppositely directed spirals (33 and 34), with said first section being arranged above the central part of discharge chamber and said second section ibeing disposed around said first section.

18. Plasma reactor as claimed in claim 17, wherein said first and second sections of said RF power input unit are connected in series one with another.

19. Plasma reactor as claimed in claim 17, wherein said first and second sections of said RF power input unit are connected in parallel one with another.

20. Plasma reactor as claimed in claim 17, wherein said first and second sections of said RF power input unit are independently connected to RF generators.

21. Plasma reactor as claimed in claim 17, wherein a magnetic system comprises at least one magnetic field source made in the form of an electromagnetic coil (26 or 27) located on a side wall (21) of the discharge chamber.

22. Plasma reactor as claimed in claim 21, wherein a magnetic system comprises at least one additional magnetic field source made in the form of electromagnetic coil arranged on an end wall of discharge chamber on which is located said RF power input unit.

23. Plasma reactor as claimed in claim 17, wherein a magnetic system includes at least one magnetic field source made in the form of one or several permanent magnets arranged on a side wall of discharge chamber.

24. Plasma reactor as claimed in claim 17, wherein a magnetic system includes at least one magnetic field source and a magnetic circuit, with said magnetic field source being arranged intermediate a discharge chamber side wall and a magnetic circuit.

25. Plasma generating apparatus comprising a discharge chamber with a gas distributor (23), a magnetic system for generating in said discharge chamber of a stationary inhomogeneous magnetic field, a RF power input unit with at least two sections, each being made in the form of spiral electrical conductors (33 and 34) with coils arranged on the outside of at least one dielectric wall (22) of discharge chamber, is characterized in that first and second sections of said RF power input unit are made in the form of oppositely directed spirals (33 and 34), with said first section being arranged above a central part of discharge chamber and said second section being positioned around said first section.

26. Apparatus as claimed in claim 25, wherein first and second sections of said RF power input unit are connected in series one with another.

27. Apparatus as claimed in claim 25, wherein first and second sections of said RF power input unit are connected in parallel one with another.

28. Apparatus as claimed in claim 25, wherein first and second sections of said RF power input unit are independently connected to RF generators.

29. Apparatus as claimed in claim 25, wherein a magnetic system includes at least one magnetic force source made in the form of an electromagnetic coil (26 or 27) located on a side wall (21) of discharge chamber.

30. Apparatus as claimed in claim 29, wherein a magnetic system includes at least one additional magnetic field source made in the form of an electromagnetic coil arranged on an end wall of discharge chamber on which is arranged said RF power input unit.

31. Apparatus as claimed in claim 25, wherein a magnetic system includes at least one magnetic field source made in the form of one or several permanent magnets arranged on a side wall of discharge chamber.

32. Apparatus as claimed in claim 25, wherein a magnetic system includes at least one magnetic field source and a magnetic circuit, with said magnetic field source being arranged intermediate said side wall of discharge chamber and said magnetic circuit.

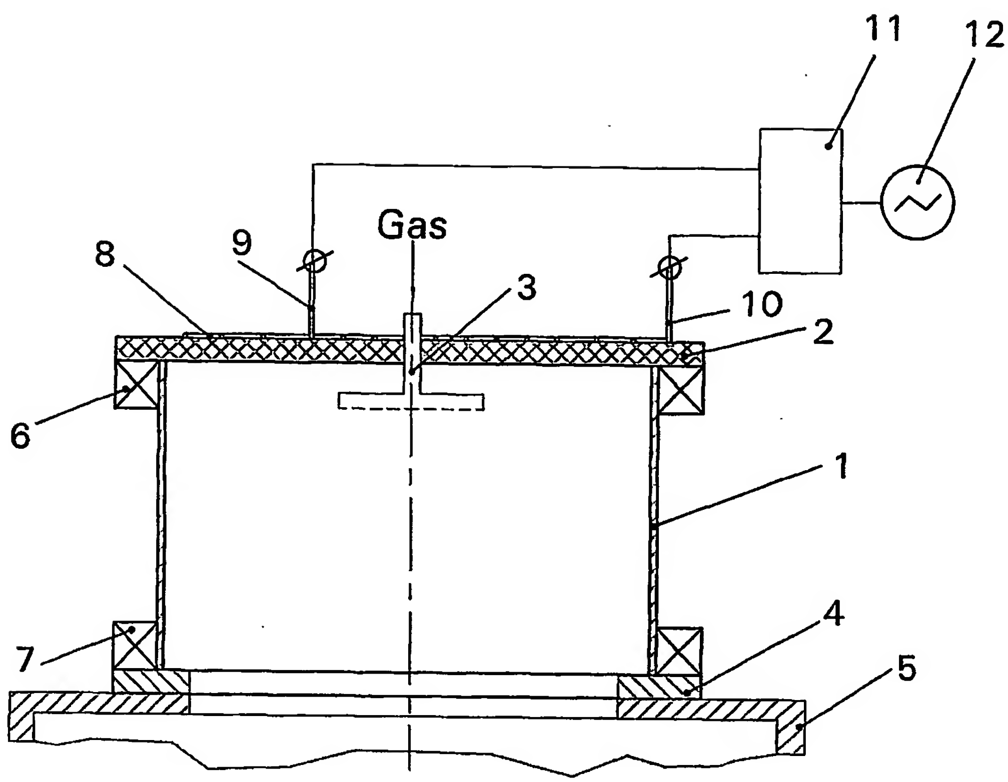


Fig. 1

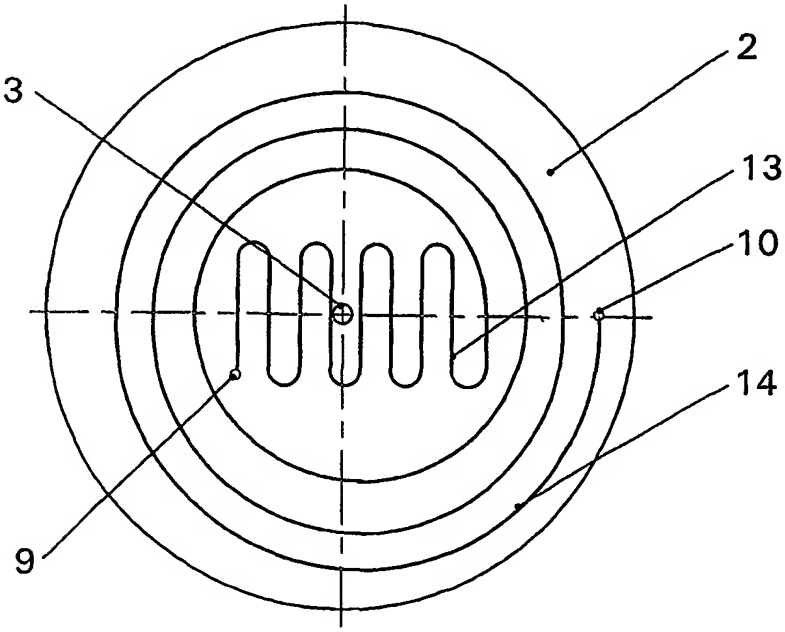


Fig. 2

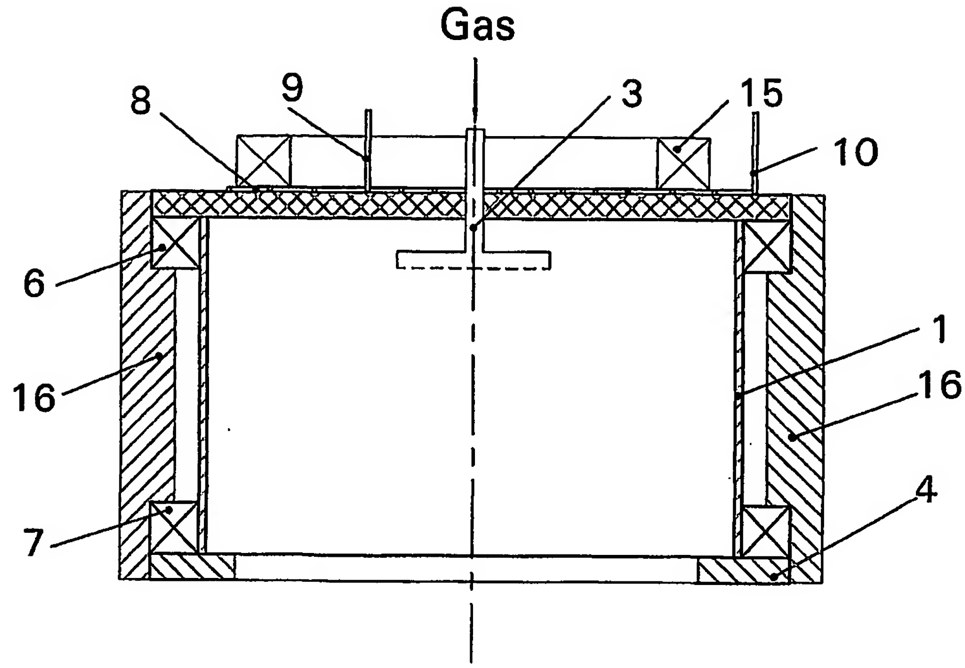


Fig. 3

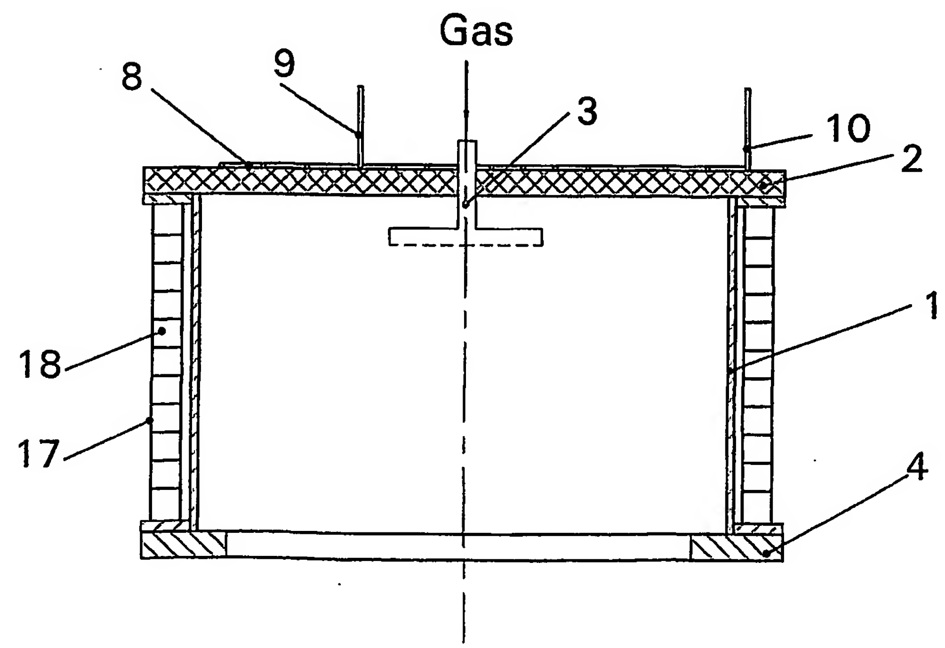


Fig. 4

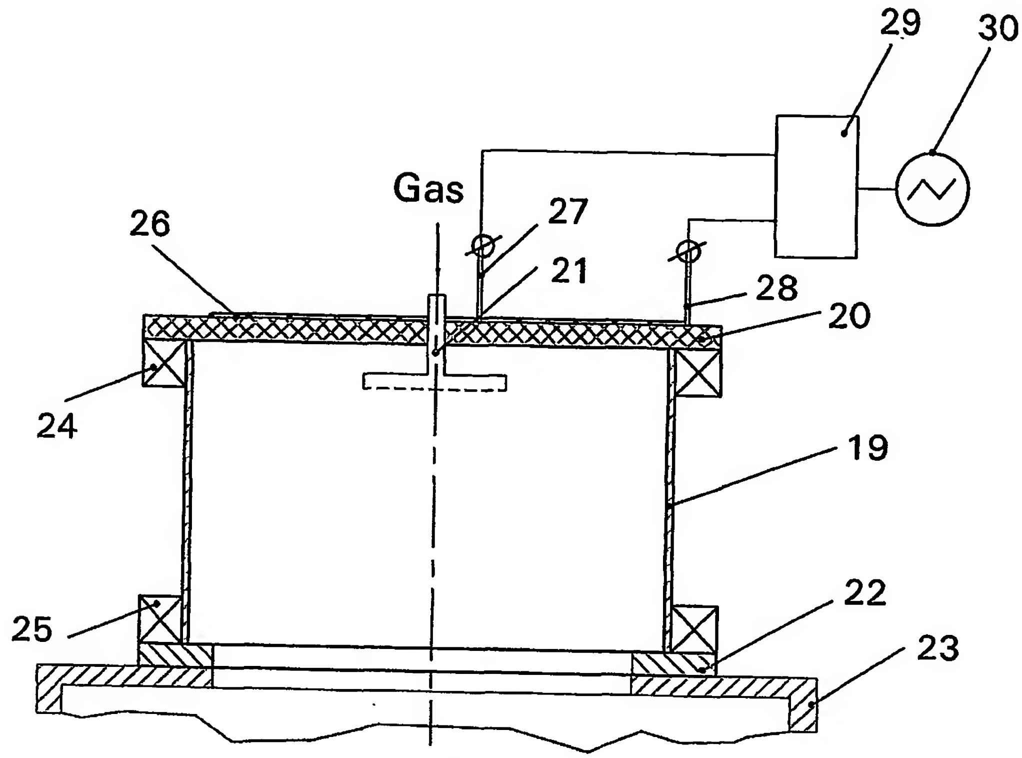


Fig. 5

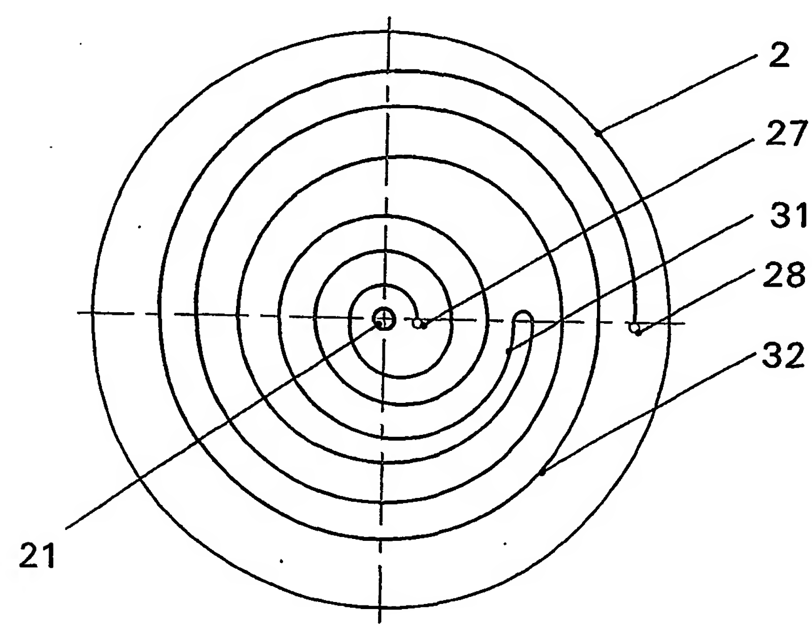


Fig. 6